The biomass may not in itself be converted to the product (such as an alcohol), or may be partially or fully converted to the product along with the low molecular weight sugar.

In instances where the biomass is partially converted, the surface area and porosity of the biomass is increased relative to the surface area and porosity of the starting biomass, which can advantageously increase the conversion rate of the low molecular weight sugar to the product.

In some cases, the biomass may be the remnants of a cellulosic or lignocellulosic material that has been saccharified, e.g., lignin and/or other materials that are left over after cellulose has been converted to sugar.

In one aspect, there is provided a method comprising: contacting a low molecular weight sugar, in a medium, with a sheet comprising oxidized biomass fibers and a fermenting microorganism immobilized on the fibers, and fermenting the low molecular weight sugar under conditions suitable for converting said sugar to an organic acid by the fermenting microorganism, wherein the biomass fibers have been oxidized in an oxidizing medium by an oxidation method selected from the group consisting of: 5 to 60 Mrad irradiation, chemical oxidation at a pH below about 5.5, sonication and pyrolysis.

In ~~one~~ another embodiment~~aspect~~, the ~~invention~~ disclosure features a method that includes utilizing a microorganism and/or enzyme that is immobilized on a biomass material, e.g., functionalized biomass fibers, to convert a carbohydrate, e.g., a low molecular weight sugar, to a product. By "immobilized," it is meant that the microorganism and/or enzyme is bonded, directly or indirectly (e.g., through a chemical linker), to the fibers by covalent, hydrogen, ionic, or equivalent bonding, and/or by mechanical interaction, e.g., between the microorganism and pores of the biomass material, e.g., fibers. Bonding may be created, e.g., by electrically polarizing the biomass material. The interaction can be permanent, semi-permanent, or fleeting. Mechanical interaction may include the microorganism or enzyme nesting in or clinging to pores or other sites of the biomass material.

Some implementations include one or more of the following features.

Converting can include allowing the microorganism to convert at least a portion of the low molecular weight sugar to an alcohol, e.g., ethanol or butanol, or to a hydrocarbon or hydrogen. Converting may include fermentation. The microorganism

may comprise a yeast, e.g., S. cerevisiae and/or P. stipitis, or a bacterium, e.g., Zymomonas mobilis. The method may further include irradiating the biomass fibers, e.g., with ionizing radiation, for example using a particle beam. The biomass fibers may have a BET surface area of greater than 0.25 m^2/g, and/or a porosity of at least 70%. The biomass fibers may be derived from a biomass material that has internal fibers, and that has been sheared to an extent that its internal fibers are substantially exposed.

In another ~~aspect~~embodiment, the ~~invention~~ disclosure features a mixture that includes a biomass material having polar functional groups, a microorganism having complementary attractive functional groups, and a liquid medium.

In a further ~~aspect~~embodiment, the ~~invention~~ disclosure features a composition comprising biomass fibers having functional groups, and a microorganism having complementary attractive functional groups, the microorganism being immobilized on the biomass fibers.

The ~~invention~~ disclosure also features a method that includes converting a low molecular weight sugar, or a material that includes a low molecular weight sugar, in a mixture with a biomass, a microorganism, and a solvent or a solvent system, e.g., water or a mixture of water and an organic solvent, to a product. Examples of solvents or solvent systems include water, hexane, hexadecane, glycerol, chloroform, toluene, ethyl acetate, petroleum ether, liquefied petroleum gas (LPG), ionic liquids and mixtures thereof. The solvent or solvent system can be in the form of a single phase or two or more phases. The biomass can be, e.g., in fibrous form.

In some instances, having a biomass material (e.g., treated by any method described herein or untreated) present during production of a product, can enhance the production rate of the product. Without wishing to be bound by any particular theory, it is believed that having a solid present, such as a high surface area and/or high porosity solid, can increase reaction rates by increasing the effective concentration of solutes and providing a substrate on which reactions can occur.

In some embodiments, a biomass material that has been irradiated, oxidized, chemically treated, mechanically treated, sonicated, steam exploded and/or pyrolyzed, can be added to a low molecular weight sugar fermentation process, e.g., to enhance fermentation rate and output.

For example, an irradiated or an un-irradiated biomass material, e.g., a paper fiber, can be added to a fermentation process, such as during a corn-ethanol fermentation or a sugarcane extract fermentation, to increase the rate of production by at least 10, 15, 20, 30, 40, 50, 75, 100 percent or more, e.g., at least 150 percent, or even up to 1000 percent. Conversion, e.g., fermentation, can exhibit a percent performance, as defined in the Examples herein, of at least 140%, in some cases at least 170%.

The biomass material can have a high surface area, high porosity, and/or low bulk density. In some embodiments, the biomass is present in the mixture from about 0.5

WHAT IS CLAIMED IS:

1. A method comprising:

~~converting~~ contacting a low molecular weight sugar, in a medium, with a sheet comprising oxidized biomass fibers and a fermenting microorganism immobilized on the fibers, and

fermenting the low molecular weight sugar under conditions suitable for converting said sugar to an organic acid by the fermenting microorganism, wherein

the biomass fibers have been oxidized in an oxidizing medium by an oxidation method selected from the group consisting of; 5 to 60 Mrad irradiation, chemical oxidation at a pH below about 5.5, sonication and pyrolysis. ~~to a product, utilizing a microorganism and/or an enzyme that is immobilized on biomass material.~~

2. The method of claim 1 wherein the wherein the organic acid is selected from the group consisting of butyric acid, lactic acid, acetic acid, propionic acid, succinic acid, 3-hydroxypropionic acid, a salt of any of these acids and mixtures of any of the acids and respective salts.~~biomass material comprises functionalized biomass fibers.~~

3. The method of claim ~~1 or~~ 2 wherein the organic acid is butyric acid.~~converting comprises allowing the microorganism to convert at least a portion of the low molecular weight sugar to a hydrocarbon, alcohol, or hydrogen.~~

4. The method of claim ~~3~~ 2 wherein the organic acid is lactic acid.~~alcohol comprises ethanol.~~

5. The method of claim 1 further comprising fermenting the organic acid to an alcohol.~~any of the above claims wherein the microorganism comprises a yeast.~~

6. The method of claim 5 wherein the alcohol is butanol.~~yeast is selected from the group consisting of S. cerevisiae and P. stipitis.~~

7. The method of claim 1 wherein the fibers have a nano-scale average particle size.~~any of the above claims wherein the microorganism comprises a bacterium.~~

8. The method of claim ~~7~~ 1 wherein the microorganism is a bacterium ~~comprises Zymomonas mobilis~~.

~~9. The method of claim 2 further comprising irradiating biomass fibers to produce the functionalized biomass fibers.~~

~~10~~9. The method of claim 1 wherein the fibers have been oxidized by irradiation and the irradiation is ~~9 wherein irradiating comprises irradiating~~ with ionizing radiation.

~~11~~10. The method of claim 9 wherein irradiating is performed using a particle beam.

~~12~~11. The method of ~~any of the above~~ claim 1~~s~~ wherein the biomass ~~material~~ fibers comprise~~s~~ a cellulosic or lignocellulosic material.

~~13. The method of claim 2 wherein the biomass fibers have a BET surface area of greater than 0.25 m^2/g.~~

~~14. The method of any of the above claims wherein converting comprises fermentation.~~

~~15~~12. The method of claim ~~2~~1, wherein the biomass fibers are derived from biomass selected from the group consisting of paper, paper products, paper waste, wood, particle board, sawdust, agricultural waste, sewage, silage, grasses, rice hulls, bagasse, jute, hemp, flax, bamboo, sisal, abaca, straw, corn cobs, corn stover, switchgrass, alfalfa, hay, coconut hair, cotton, seaweed, algae, and mixtures thereof.

~~16~~13. The method of claim ~~2~~1 wherein the biomass fibers are derived from a biomass feedstock that has internal fibers, and that has been sheared to an extent that its internal fibers are substantially exposed.

~~17~~14. The method of claim ~~2~~1 wherein the biomass fibers have a porosity greater than 70%.

~~18. The method of any of the above claims wherein the converting step exhibits a % performance of at least 140%.~~

~~19. The method of claim 2 further comprising recovering the biomass fibers after conversion and reusing the fibers in a second, subsequent conversion process.~~

~~20. The method of claim 2 wherein the biomass fibers are provided in the form of a single or multi-layer sheet.~~

~~21. The method of claim 2 wherein the biomass fibers are provided in the form of a fibrous material that is overlaid, folded, or in the form of a screen or mesh.~~

~~22~~15. The method of claim ~~2~~ 1 wherein the biomass fibers are extruded or coextruded.

~~23. The method of claim 2 wherein the fibers have a nano-scale average particle size.~~

~~24. The method of any of the above claims wherein converting comprises introducing the low molecular weight sugar and biomass to a liquid medium, and the method further comprises pretreating the fibers or a fibrous material containing the fibers with a microorganism and/or enzyme prior to introducing the fibers or materials to the medium.~~

~~25. A mixture comprising:~~

~~a biomass material having polar functional groups,~~

~~a microorganism and/or enzyme having complementary functional groups, and~~

~~a liquid medium.~~

~~26. A composition comprising biomass fibers and a microorganism and/or enzyme immobilized on the biomass fibers.~~

~~27. The composition of claim 26 wherein the fibers have functional groups, and the microorganism and/or enzyme has complementary functional groups.~~

16. The method of claim 1 wherein the sheet is overlaid, folded, or in the form of a screen or mesh.

17. The method of claim 1 further comprising recovering the biomass fibers after fermenting and reusing the fibers in a second, subsequent fermentation process.

18. The method of claim 1 wherein the sheet is a multilayer sheet.

19. The method of claim 9 wherein irradiating is performed using an electron beam.

20. The method of claim 1 wherein the oxidized biomass fibers are produced by oxidizing a starting fibrous biomass to an extent that functional groups are generated on the starting fibrous material.

21. The method of claim 7 wherein the functional groups are selected from the group consisting of hydroxyl groups, aldehyde groups, ketone groups, ester groups or carboxylic acid groups.

22. The method of claim 7 wherein the microorganism is bonded to the oxidized biomass fibers through the functional groups.